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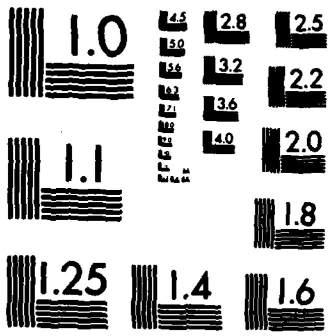
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A study was conducted to verify whether high temperatures (from 41°C to 54°C) (normal lighting) at different wind movements (up to 9 $m \cdot s^{-1}$) at constant dew points affect the wet globe temperature index measured with a Botsball. A new meter (Reuter-Stokes) was also tested which digitizes the values of globe temperature, air and wet bulb (ventilated) temperatures. The values are integrated to a wet bulb globe temperature (WBGT). The readings from this meter, as well as the Botsball, were tested against a Yellow Springs Instrument (YSI) standard set-up for natural wet bulb, air and globe temperatures, and against


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UNITED STATES OF AMERICA

# BIOPHYSICAL EVALUATION OF THE WET GLOBE TEMPERATURE INDEX (BOTSBALL) AT HIGH AIR MOVEMENTS AND CONSTANT DEW POINT TEMPERATURE

by

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## ABSTRACT

US-2

A study was conducted to verify whether high temperatures (from 41°C to 54°C) (normal lighting) at different wind movements (up to 9 $m \cdot s^{-1}$) at constant dew points affect the wet globe temperature index measured with a Botsball. A new meter (Reuter-Stokes) was also tested which digitizes the values of globe temperature, air and wet bulb (ventilated) temperatures. The values are integrated to a wet bulb globe temperature (WBGT). The readings from this meter, as well as the Botsball, were tested against a Yellow Springs Instrument (YSI) standard set-up for natural wet bulb, air and globe temperatures, and against psychrometric values. All data were collected on-line by a computer in an all-weather tropic/wind chamber and procedures were designed according to standard practices (ASHRAE Fundamentals). The data were subjected to statistical analysis, reversing the order in which one index was the dependent or independent variable. A multiple correlation analysis was also done in which the Reuter-Stokes (R-S) WBGT, YSI WBGT and Botsball readings were the dependent variables versus psychrometric readings of ambient air temperature and ambient water vapor pressure. The Botsball tracked wet bulb temperature more closely to the R-S ventilated wet bulb than the YSI natural wet bulb. The Botsball essentially reads a wet bulb temperature which, with low humidity and a wind (> 3 $m \cdot s^{-1}$), is only slightly elevated above the true wet bulb temperature. The wet bulb thermometer in the WBGT is only slightly lower (true wet bulb temperature), but accounts for 70% of WBGT; 20% of the globe temperature reading (which can run 20°C above ambient in sunlight even in a wind) is also added to obtain WBGT. Up to 7 $m \cdot s^{-1}$ wind speed and 54°C (130°F), there is no effect of air movement if the Botsball is wetted adequately and at a moderate RH (> 15%RH). High coefficients of determination ($r^2$) were evident for wind speeds up to 9 $m \cdot s^{-1}$ (20 mph) using the R-S and YSI meters for WBGT (°C): R-S WBGT=0.966 (calc WBGT)+1.31, $r^2$=0.991; YSI WBGT=0.999 (calc WBGT)+0.03, $r^2$=0.999; and a lesser coefficient of determination in using the Botsball:calc WBGT=1.2037 (Bots)-3.74, $r^2$=0.975. Based on these analyses, a hypothetical environment of 45°C/11 Torr desert (15%RH) for high wind speeds would give: R-S WBGT=28.6°C or 83.4°F; YSI WBGT=23.2°C or 73.7°F; and Botsball=19.7°C or 67.4°F. Thus, in the desert, the Botsball can likely read some 4°C to 9°C (6 to 16°F) lower than WBGT. However, in a hot-wet environment of 35°C/25 Torr (60% RH), these values become: R-S WBGT=29.9°C or 85.8°F; YSI WBGT=29.1°C or 84.3°F; and Botsball=27.3°C or 81.1°F. Only a 3°F disparity of the Botsball reading to WBGT exists in humid environments with wind. Further biophysical measurements are warranted which are supported by physical analysis of thermal exchanges aimed at defining the conditions under which Botsball readings are misleading and the magnitudes of differences between WGT and WBGT under varied conditions.

## 1. INTRODUCTION

Quite a few studies have examined the practicality of using empirical indices (i.e., devices which measure thermal stress as a function of wet and dry bulb temperature) to determine degree of severity of a thermal environment (1,2,3). Several of these, the Temperature-Humidity Index THI of Thom, Weather Bureau (4), the Oxford Index WD (85) (5), and the Wet Bulb Globe Temperature WBGT (6) have common features. They are all simple linear functions and weighted averages of dynamic ($T_{wb}$) or natural ($T_{nwb}$) wet bulb and operative temperature of the environment. The WBGT was developed by Yaglou and Minard (6) for use by US Marine Corps Training Centers.

As specified in the Armed Forces Technical Bulletin, Medical, 175 (7), the WBGT Index was chosen to identify the environment because it is simple as far as measurements needed for its determination. It also consolidates into a single value the four environmental factors, namely, the dry bulb temperature ($T_{db}$), the ambient water vapor pressure or relative humidity (RH), the mean radiant temperature ($T_{mr}$), and the air velocity (V). For outdoor environments with solar load:

$$WBGT = 0.7\ T_{nw} + 0.2\ T_g + 0.1\ T_a$$

where

$T_{nw}$ = natural wet-bulb temperature obtained with a wetted sensor exposed to the natural air movement;

$T_g$ = temperature in the center of a 15 cm (6 in) diameter hollow copper sphere, painted on the outside with a matte black finish (globe temperature);

$T_a$ = dry bulb temperature.

One aspect which makes the WBGT Index attractive is the fact that the air velocity need not be measured, since its value is reflected in the measurement of the natural wet bulb temperature $T_{nw}$.

One of the deficiencies in the WBGT Index is the fact that the natural wet bulb temperature is not a thermodynamic property. Consequently, different combinations of environmental parameters could have the same WBGT.

The instruments required for determining the WBGT Index, for an indoor environment, are the natural wet bulb and the globe thermometers. If both thermometers are placed in an environment having a certain $T_{db}$, $T_{mr}$, RH or vapor pressure, and V, and if both thermometers reach equilibrium with the environment, one can write two equations which govern the heat and mass transfer of both thermometers.

a. Transfer Characteristics

At equilibrium, the energy exchange by convection and radiation, with the surrounding environment, is dissipated by evaporation.

Therefore, (8,9),

$$h_c(T_{db}-T_{nw})+\epsilon_{nw}\,\sigma(T_{mr}^4-T_{nw}^4)=h_e(P_{snw}-RH\cdot P_{sa}) \qquad (1)$$

where

$T_{db}$ = dry bulb temperature of the environment, $^{o}K$

$T_{nw}$ = natural wet bulb temperature, $^{o}K$

$T_{mr}$ = mean radiant temperature, $^{o}K$

$\epsilon_{nw}$ = emissivity of the surface of the wetted wick

$P_{snw}$ = saturated water vapor pressure at $T_{nw}$, Torr

$P_{sa}$ = saturated water vapor pressure at $T_{dp}$, Torr

$h_c$ = convective heat transfer coefficient, $W/(m^2\cdot{}^{o}C)$

$h_e$ = evaporative heat transfer coefficient, $W/(m^2\cdot Torr)$

RH = relative humidity ratio

$\sigma$ = Stefan-Boltzman constant, $5.67 \times 10^{-8}\ W\cdot m^{-2}\cdot K^{-4}$

The convective heat transfer coefficient of the natural wet bulb can be calculated by (8)

$$h_c = 42.024\ V^{0.466} \qquad W \cdot m^{-2} \cdot C^{-1} \qquad (2)$$

where V is the air velocity in $m \cdot s^{-1}$. The evaporative heat transfer coefficient is related to the convective heat transfer coefficient by

$$h_e = 2.2\ h_c \qquad (3)$$

where 2.2 is the modified Lewis relation in $^{o}C \cdot Torr^{-1}$.

At equilibrium with the surrounding environment in the globe thermometer, the energy received by radiation is dissipated by convection. Therefore,

$$h_{c,g}\ (T_g - T_{db}) = \varepsilon_g \cdot \sigma (T_{mr}{}^4 - T_g{}^4) \qquad (4)$$

where

$T_g$ = globe temperature, $^{o}K$

$\varepsilon_g$ = globe surface emissivity.

The convective heat transfer coefficient from the surface of the globe can be calculated by

$$h_{c,g} = 15.889\ V^{0.6}, \qquad W \cdot m^{-2} \cdot C^{-1} \qquad (5)$$

where V is in $m \cdot s^{-1}$.

The emissivities of $\varepsilon_{nw}$ and $\varepsilon_g$ are assumed equal to unity. If the four environmental factors, namely, $T_{db}$, $T_{mr}$, RH and V are specified, Eqs. (1) and (4) can be solved by iteration for $T_{nw}$ and $T_g$, respectively, from which the WBGT can be calculated.

b. <u>Wet Globe Temperature Index</u>

Another useful empirical index has been developed for use in the military (2) with some success. This is known as the "Botsball" originally derived by

Botsford (10) which consists of a dial thermometer with a heat sensor enclosed by a 6 cm (2.36 inch) black globe encircled with black cloth. In 1980, USARIEM researchers (2) ran a study to compare the usefulness of this device as a simple, cheap and portable alternative to WBGT. A regression equation was developed between the two indices in which

$$\text{WBGT}, (^{\circ}\text{C}) = 1.044\,(\text{WGT}) - 0.187 \quad r^2 = 0.96. \qquad (6)$$

This study showed that the Botsball could adequately "substitute" for heat stress conditions over the range of windspeeds of $\leq 7$ $m \cdot s^{-1}$ (15.6 miles/hr). However, data in the study were only taken over a 3 hr period. In this study, the tendency was seen in which the Botsball response was decreased at high windspeeds from < 3 $m \cdot s^{-1}$ (7.8 miles/hr) to up to 7 $m \cdot s^{-1}$ (15.6 miles/hr). This would be expected because of the high mass transfer coefficient from the wicking surface. Thus, the consequent WBGT in Eq 6 is interpreted at a lower level which tends to offset actual heat stress values which might compromise actual conditions affecting troops in maneuvers.

The purpose of the present study was to verify whether high air temperatures (in normal lighting) at different wind movements up to 9 $m \cdot s^{-1}$ (20 mph) at constant dew point temperatures modify the wet globe temperature index within the Botsball. The adequacy of a new meter for direct measurement of WBGT was also tested. Theoretical implications for solar load and rational indices have also been included.

## 2. METHODS

All experiments were in a tropic/wind chamber situated at the US Army Natick Research and Development Center. The instruments were placed on a cross width plane of the laminar flow part of the chamber lined up roughly at chest site of a standard man (178 cm) facing windward. A general Eastern automatic dry bulb and optical dew point measuring system was situated on the extreme right side of such a plane of the standard man followed by the Botsball, a 15 cm Black Globe, a Reuter-Stokes (R-S) meter and a Yellow Springs Instrument (YSI) kit containing a 15 cm black globe, dry bulb and natural wet bulb thermometer. The latter kit was set up as described in TB MED 175 (7) and the other instruments were arranged according to standard practices in the Fundamentals Handbook of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Each instrument in effect viewed a similar microenvironment separated by 15 cm from the mid point of any other instrument. The Botsball and a black copper 15 cm globe were suspended from the ceiling fixed on the same plane as the other instruments.

A three-cup anenometer used to measure windspeed was placed 1 meter in front of the above instruments and was continuously read by a Hewlett-Packard (HP) universal counter. All instruments except the R-S and YSI meters were continuously read on-line in to a HP 9836 computer. All transducer units ($T_g$ and $T_{wb}$) of these two meters were scanned manually every 20 min at which time the Botsball was also wetted. Experiments were at constant dry bulb temperatures of 40.6°C, 46.1°C, and 54.4°C at a constant dew point temperature of 25.5$\pm$0.9 °C which gave a %RH of 44, 38 and 28%, respectively. Each day at a given constant environment, air movement was varied from 1.3 $m \cdot s^{-1}$, 6.7 $m \cdot s^{-1}$ or 9.0 $m \cdot s^{-1}$ and kept constant for 2 hours. The last hour's block of data were subjected to statistical analysis which included single linear regression and multiple regression analysis. For single linear regression analysis, a given index was assigned as the independent variable and the order reversed with the appropriate dependent variable. A multiple correlation analysis was also done in which values of the R-S WBGT, YSI WBGT and

Botsball readings as the dependent variables were run against psychrometric readings of ambient air temperature and ambient water vapor pressure.

3. RESULTS AND ANALYSIS

Figure 1 shows that the Botsball, in the ranges of air movements from 1.3 to 9 $m \cdot s^{-1}$ and mean radiant temperatures ($\bar{T}_{mr}$) of 44 to 58°C, essentially tracked the ventilated wet bulb function of the R-S meter more closely than the natural wet bulb of the YSI standard meter. Typically, in our study up to a wind speed of 7 $m \cdot s^{-1}$ at $T_a$ of 54.4°C (130°F) no effect of air movement was evident provided the Botsball cloth is 100% wetted and the ambient is at a moderate RH level (<15% RH).

Table 1 shows that almost as high coefficients of determination ($r^2$) were found using either the R-S or YSI meters in the indoor calculation of WBGT (i.e., 0.7 natural wet bulb + 0.3 dry bulb temperatures). This calculated WBGT was strongly correlated to the Botsball values for the environmental conditions spanning this test. Both the slope and intercept are different from that obtained in Onkaram et.al. (2) although our coefficient of determination (0.975) is higher than that obtained in their study (0.96). However, their study was conducted outdoors at ambient air temperatures from 18.7 to 34.6°C and wind speeds covering 0 to 7 $m \cdot s^{-1}$. The critical factor in the Botsball determination is probably not due to wind in indoor environments but rather to low humidity on the black cloth surrounding the globe coupled with high evaporative cooling. This fact is confirmed in the weightings given to ambient water vapor pressure ($P_a$, Torr) in the multiple correlation analysis of these indices (Table 2). Both the YSI and Botsball have 35 to 40% greater weightings to $P_a$ than does the R-S meter.

Table 3 shows the coefficients of determination using the Botsball index, R-S meter or calculated WBGT as the dependent variable and other variables as the independent variable. Also included as the independent variable is the WBGT obtained by Gagge and Nishi (4) from their multiple correlation analysis with $T_a$, $P_a$. Our Botsball measurement at high wind and air temperature ranges of 40.6°C to 54.5°C tracked the $T_{wb}$ of the R-S meter more adequately than the YSI meter's natural wet bulb. However, the Botsball was more highly correlated with the WBGT of the YSI meter than with the WBGT index of the R-S meter. The Botsball index was not as highly correlated with the WBGT equation of Gagge and Nishi ($r^2$=0.915). However, the calculated WBGT (for indoor weighting) was highly correlated with WBGT's from the YSI ($r^2$=0.99), R-S ($r^2$=0.99) meters and the Gagge and Nishi equation ($r^2$=0.97). Table 4 is a prediction of the Botsball and WBGT for outdoor use based on heat transfer properties of the two indices. It is clear that no appreciable effect of wind speed exists on the WBGT to Botsball differences. As the RH increases, however, the WBGT to Botsball differences are significantly reduced. Furthermore, the WBGT to Botsball differences are exacerbated as dry bulb temperature increases.

Based on these assumptions using the combination of data from the above equations, a hypothetical environment of 45°C/11 Torr (15% RH) desert environment would give values from the combined indices for:

R-S WBGT = 28.6°C or 83.4°F

YSI WBGT = 23.2°C or 73.7°F

Present study Botsball = 19.7°C or 67.4°F

Onkaram et.al. equation (2) of the Botsball

= 20.4°C or 68.6°F

Thus, in a desert environment the Botsball reading could read some 3- 9°C (6 to 16°F) lower than true WBGT whatever index one uses. However, in a hot-wet environment of 35°C/25 Torr (RH 60%), these values become:

R-S WBGT = 29.9°C or 85.8°F

YSI WBGT = 29.1°C or 84.3°F

Present study Botsball = 27.3°C or 81.1°F

Onkaram Botsball eq. = 28.3°C or 82.9°F.

Therefore, in a moderately humid environment only a 1.3 or 2.1°C or (2.3 to 3.8°F) disparity exists in the Botsball reading compared to true WBGT.

One critical rational index which may be developed from the above indices is operative temperature ($T_o$). Operative temperature (11) is simply an average of mean radiant temperature ($\bar{T}_{mr}$) and ambient dry bulb temperature weighted by their respective heat transfer coefficients and would represent how an individual senses the degree of thermal stress of the total environment as a single temperature due to solar radiation (1), air movement and air temperature. Any black globe in thermal equilibrium with its radiant environment, will gain radiant heat from various heated sources but balance this by convective heat loss. As such Eq 4 of the globe becomes an average $\bar{T}_{mr}$ affecting man. This is (2) equivalent to the effective radiant field (ERF, $W \cdot m^{-2}$) (12) in which

$$ERF_g = (h_{r,g} + h_{c,g})(T_g - T_a). \qquad (7)$$

This ERFg however must be modified by shape ($f_e$) and skin-clothing-absorptance ($\alpha K$) factors of humans relative to any conventional sized black sphere such that

$$ERF\ (human) = f_e \cdot \alpha_K \cdot ERF_g \qquad (8)$$

where the $f_e$ is the effective radiating area (ca.0.71) and is equal to $h_r/h_{rg}$. The operative temperature affecting a human in the field then becomes

$$ERF = h\,(T_o - T_a)$$

$$\text{or } T_o = k\,T_g + (1\text{-}k)\,T_a$$

where the weighting coefficient k first introduced in ref (12) becomes

$$k = \alpha k \cdot (h_{r,g} + h_{c,g})/(h_r + h_c).$$

In essence, when k is equal to 1.0, the $T_g$ of a globe would be equivalent to the operative temperature sensed by a human.

Assuming that the effective radiating area ($f_e$) for a globe of a given diameter (meter) is 1.0, at 50°C $h_{r,g}$ is 7.2 $W \cdot m^{-2} \cdot K^{-1}$, $h_{c,g}$ may be estimated by equation 5 or as in ref (12) by

$$h_{c,g} = 6.32 \cdot D^{-0.4} \cdot V^{0.5} \qquad (9)$$

where D is any globe diameter (meters) and V is air movement ($m \cdot s^{-1}$); suitable weighting coefficients for the dry globe of the Botsball (0.06 m diameter) and the conventional globe sensor (0.15 m) can be compared as a function of wind speed as shown in Table 5.

The weighting coefficient k for the conditions in the above environment becomes for a standing man:

$$k = \alpha_k \cdot 0.71\,(7.2 + 6.32 D^{-0.4} \cdot V^{0.5})/(5.2 + 8.5\,V^{0.5}) \qquad (10)$$

Table 5 shows that the uncorrected temperature of the standard 15 mm globe overestimates the true $T_o - T_a$ by 8% with V up to 1.3 $m \cdot s^{-1}$. The smaller diameter globe of the Botsball causes a greater variation in k caused by air movement. Typically as seen in Table 5, the ideal diameter is a sphere 200 mm

(8 in) which would be independent of air movement. Given theses values true operative temperature in a 9 m·s$^{-1}$ wind for the globe of the Botsball would be

$$T_o = 1.53\ T_g - 0.5\ 3\ T_a \qquad {}^{o}C \qquad (11)$$

Additionaly, a humid operative temperature can be developed for the combination of black cloth and globe of the Botsball (11). Humid operative temperature ($T_{oh}$) would be an average of the operative temperature and dew point temperature weighted by the factors $hF_{cl,b}$ and $E_s/E_{max}$ (2.2 $h_c$Fpcl, b) (1.92). The constant Fcl, b is the cloth sensible heat efficiency factor, Fpcl, b is the cloth permeation factor and $E_s/E_{max}$ is the ratio of the evaporation to maximal evaporative power of the environment by the Botsball cloth or its intrinsic level of "wettedness" (w).

$T_{oh}$ of the Botsball may therefore be defined by

$$T_{oh,b} = (A\ To + wBTdp)/C \qquad {}^{o}C \qquad (12)$$

where A = hFcl, b

B = 4.2 Fpcl, b

C = A + wB

The Botsball value of $T_{oh}$ is most efficient as an environmental index when the Botsball is, of course, 100% wet.

## 4. SUMMARY

There are always shortcomings in empirical indices. Gagge and Nishi (4) emphasize that no one all-purpose instrument can be used to estimate heat stress. As found in this present analysis definite differences exist between the WGT (Botsball index) and WBGT index values at low humidities in the presence of high solar load. Less discrepancies exist for indoor environments when neglible effects of solar load exist but mean radiant temperature does affect the globe sensor (especially when $\bar{T}_r > T_a$). Our analysis shows that the Botsball essentially tracks a wet bulb temperature which, with low dew point temperature and with winds up to 9 $m \cdot s^{-1}$, is only slightly elevated above true wet bulb temperature. The wet bulb in the standard WBGT meter is only slightly lower than true wet bulb but accounts for 70% of WBGT index. Twenty percent of the globe sensor (which may be often 20°C above ambient temperature with a solar load) is added to obtain WBGT. As such the errors are more likely to occur in the wet bulb weightings. Further biophysical measurements are needed which are supported by physical analysis of thermal exchanges aimed at defining the exact conditions under which Botsball readings become misleading and establishing what these magnitudes are on a psychrometric chart.

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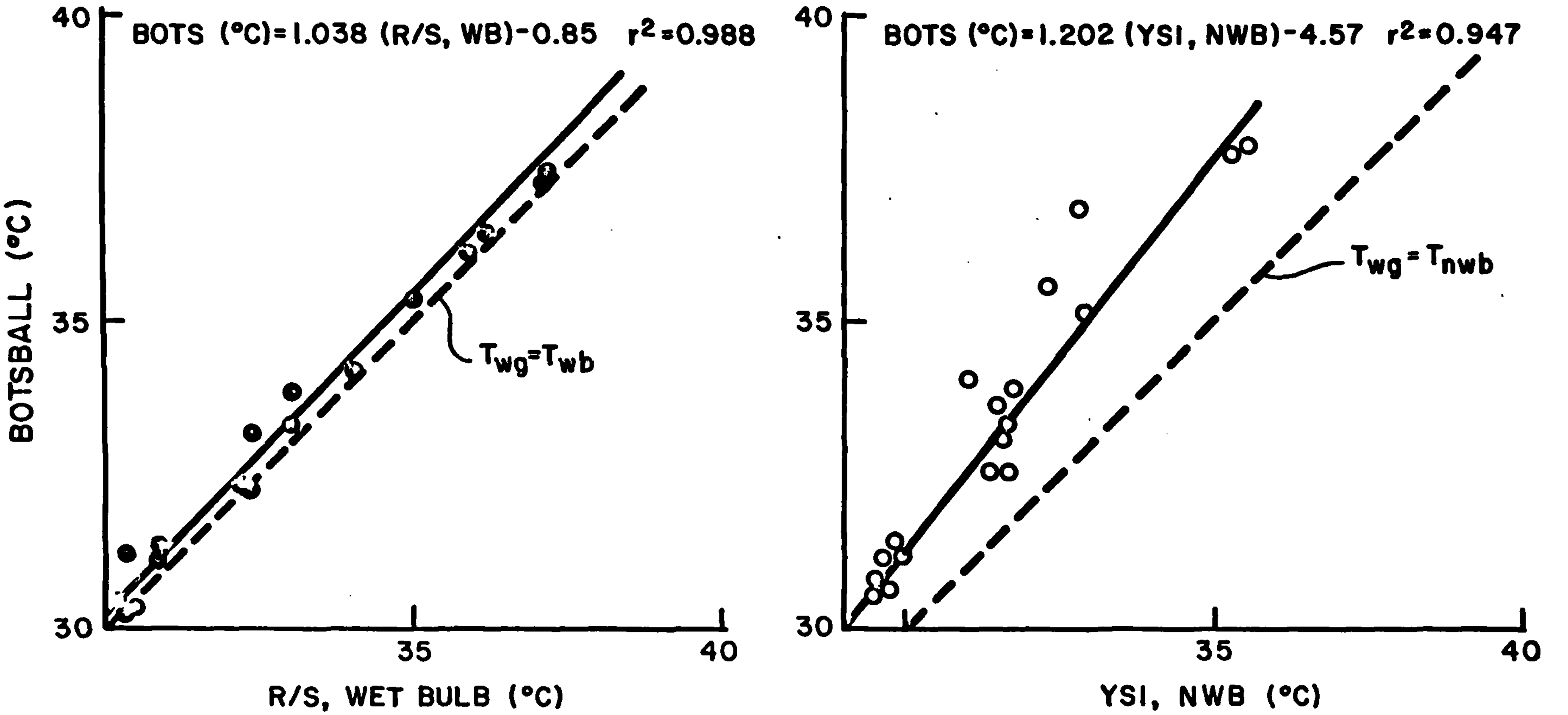
## FIGURE LEGEND

Figure 1. Comparison of the Botsball ($T_{wg}$) as a function of the wet bulb transducer ($T_{wb}$) of the Reuter-Stokes (R/S) meter and the natural wet bulb ($T_{wb}$) of the Yellow Springs (YSI) standard unit.




R/S TRACKS THERMODYNAMIC WET BULB

TABLE 1. Regression Equations between Various Indices ($V \leq 20$mph; $28 \pm 0.9^{o}C$ $T_{dp}$).

| Dependent variable | Independent variable | Equation | $r^2$ |
|---|---|---|---|
| (INDOORS) | | | |
| R/S WBGT | calc. WBGT | Y=0.966X+1.31 | 0.991 |
| YSI WBGT | calc. WBGT | Y=0.99X+0.03 | 0.999 |
| Calc. WBGT | BOTSBALL | Y=1.2037X-3.74 | 0.975 |

TABLE 2. Multiple Correlation Analysis between Various Indices (°C) and Dry Bulb ($T_a$) and Ambient Water Vapor Pressure ($P_a$, Torr).

| Index | Equation | $R^2$ |
|---|---|---|
| R/S WBGT | $0.52\,(T_a) + 0.467(P_a)+0.018$ | 0.986 |
| YSI WBGT | $0.45\,(T_a) + 0.742(P_a)-5.22$ | 0.995 |
| BOTSBALL | $0.336\,(T_a) + 0.783(P_a)-4.06$ | 0.969 |

TABLE 3. Coefficients of Determination ($R^2$) for Various Indices and Respective Transducer Units.

| DEPENDENT VARIABLE | COMPUTER | | YS I METER | | | | REUTER-STOKES METER | | *GAGGE/NISHI EQUATIONS |
|---|---|---|---|---|---|---|---|---|---|
| (°C) | $T_a$ | $T_g$ | NWB | WBGT | $T_a$ | $T_g$ | WBGT | $T_{wb}$ | WBGT |
| BOTSBALL | | | | 0.980 | | | 0.960 | | 0.915 |
| INDEX | | | 0.947 | | | | | 0.988 | |
| REUTER-STOKES: | | | | | | | | | |
| WBGT | | | | 0.984 | | | | | 0.983 |
| $T_g$ | | 0.989 | | | | 0.990 | | | |
| $T_a$ | 0.990 | | | | 0.994 | | | | |
| CALCULATED WBGT | | | | 0.990 | | | 0.991 | | 0.971 |

Gagge & Nishi ref (4) where WBGT = $0.567\ T_a + 0.288\ P_a + 3.39$; NWB is natural wet bulb

TABLE 4. Predicted (Calculated) Values of WBGT and WGT (BOTSBALL) for Full Sunlight Outdoors.

| Conditions $T_a$, %RH, $P_a$ (°C), %, Torr | Wind $m \cdot s^{-1}$ | WBGT °C | BOTSBALL °C | DIFF °C (°F) |
|---|---|---|---|---|
| 27, 50%, 13.4 | 3 | 23.29 | 20.95 | 2.24 (4.0) |
| 27, 50%, 13.4 | 10 | 22.56 | 20.15 | 2.41 (4.3) |
| 32.2, 20%, 7.2 | 3 | 23.2 | 18.8 | 4.4 (7.9) |
| 32.2, 20%, 7.2 | 10 | 22.4 | 17.8 | 4.6 (8.3) |
| 32.2, 50% 18 | 3 | 27.9 | 25.1 | 2.75 (4.9) |
| 32.2, 50%, 18 | 10 | 27.1 | 24.4 | 2.69 (4.9) |
| 50, 20%, 18.5 | 2 | 36.8 | 30.1 | 6.68 (12.0) |
| 50, 20%. 18.5 | 3 | 36.4 | 29.7 | 6.69 (12.0) |
| 50, 20%, 18.5 | 10 | 35.6 | 28.9 | 6.7 (12.1) |
| 50, 50%, 46.3 | 3 | 43.5 | 39.7 | 3.83 (6.9) |
| 50, 50%, 46.3 | 10 | 42.8 | 39.1 | 3.74 (6.7) |

full sunlight = total radiation of 665 $W \cdot m^{-2}$ at specific solar elevation of 45°, average for the contiguous U.S. (ref 3).

TABLE 5. The k Values for Air Movement (V, $m \cdot s^{-1}$) and D Values in the Botsball and Standard Globe at 50°C.

| V | Botsball (Dry Globe) (D=0.06 m) | Globe (D=0.15 m) | Hypothetical (D=0.2m) |
|---|---|---|---|
| 0.25 | 1.27 | 1.05 | 0.99 |
| 1.3 | 1.40 | 1.08 | 0.99 |
| 6.7 | 1.50 | 1.10 | 1.0 |
| 9.0 | 1.52 | 1.10 | 1.0 |

for $\alpha g = 1$

END

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